ENGLISH

TRANSLATION OF

OF INTERNATIONAL

APPLICATION AS FILED

DESCRIPTION

DUPLEXER AND COMMUNICATION DEVICE

Technical Field

The present invention relates to a duplexer and a communication device which are used in communications equipment, and more particularly to a duplexer and a communication device which are provided with a band filter formed by connecting a plurality of surface acoustic wave resonators to construct a ladder circuit.

Background Art

In general, in a surface acoustic wave element, an interdigital electrode (IDT electrode) having a plurality of electrode fingers is formed on a piezoelectric substrate. The electrode fingers of the IDT electrode are fine, and the pitch between the electrode fingers is extremely small. Therefore, when a large electric power is applied, short circuit may occur between the electrode fingers mutually and breaking may occur in the electrode fingers. Accordingly, improvement in the electric power resistance is strongly desired for the surface acoustic wave element.

Patent Document 1 described below discloses a surface acoustic wave element with increased electric power resistance. Here, on a 64° Y-X-cut $LiNbO_3$ substrate, an IDT

electrode is formed by laminating a Ti foundation electrode layer formed through epitaxial growth and an Al electrode layer formed further through epitaxial growth on the Ti foundation electrode layer. The (111) face of the crystal of the Al electrode layer, the (001) face or (100) face of the crystal of the Ti foundation electrode layer, and the (001) face of an $LiTaO_3$ substrate are aligned parallel, whereby it has been considered that the electric power resistance is increased.

On the other hand, in a duplexer used for a mobile phone based on the W-CDMA system, a plurality of surface acoustic wave elements are connected to construct a reception-side band filter and a transmission-side band filter. Fig. 20 shows an example of such a related-art duplexer circuit. In Fig. 20, an area surrounded by a dashed line constructs a duplexer 201. The duplexer 201 includes an antenna terminal 201a. The antenna terminal 201a is connected to an antenna 202. Furthermore, an external inductance 203 and an external capacitor 204 are connected between the antenna terminal 201a and the antenna 202. To be specific, the inductance 203 is inserted between the antenna terminal 201a and the antenna 202 and the capacitor 204 is connected between a connection point between the antenna 202 and the inductance 203 and a ground potential.

Meanwhile, the duplexer 201 includes a transmission-side band filter 201A and a reception-side band filter 201B. In the transmission-side band filter 201A, a plurality of serial arm resonators Sa to Sc and parallel arm resonators Pa and Pb are connected to construct a ladder circuit. Herein, an inductance element 205 is connected in parallel with respect to the serial arm resonator Sc in the last pole. Also, in the reception-side band filter 201B as well, a plurality of serial arm resonators Sd to Sf are connected to a plurality of parallel arm resonators Pc and Pd to achieve a ladder circuit. Herein, an inductance element 206 is connected in parallel with respect to the serial arm resonator Se in the center.

Furthermore, inductance elements 207 and 208 are connected between the parallel arm resonators Pa and Pb of the transmission-side band filter and the ground potential.

Patent Document 1: Japanese Unexamined Patent Application Publication No. 2002-353768

Disclosure of Invention

With the surface acoustic wave element having the electrode construction described in Patent Document 1, the electric power resistance can be increased as described above. However, when the surface acoustic wave elements described in Patent Document 1 are used for the serial arm

resonators Sa to Sc, the parallel arm resonators Pa and Pb, the serial arm resonators Sd to Sf, and the parallel arm resonators Pc and Pd of the duplexer 201 shown in Fig. 20, the electric power resistance is increased, but it is revealed that an out-of-band attenuation is not sufficient and also an isolation characteristic is not satisfactory. This will be described with reference to Figs. 21 to 23.

The surface acoustic wave elements having the electrode construction described in Patent Document 1 are used for the serial arm resonators Sa to Sc and Sd to Sf, and the parallel arm resonators Pa to Pd, and a 64° rotated, Y-cut $LiNbO_3$ substrate is used to fabricate the duplexer 201. Fig. 21 shows a frequency characteristic of the transmission-side band filter 201A and Fig. 22 shows a frequency characteristic of the reception-side band filter 201B. It should be noted that curved lines on the lower side of Figs. 21 and 22 represent the frequency characteristics in pass bands shown through magnification of the corresponding frequency characteristics. Then, Fig. 23 shows an isolation characteristic of the duplexer 201.

In the duplexer of the mobile phone based on the W-CDMA method, the attenuation in the outer neighborhood of the pass band on the high pass side of 1920 MHz to 1980 MHz, namely, in the pass band of the reception-side band filter is required to be at least 40 dB. In view of the above, in

the transmission-side band filter 201A shown in Fig. 20, by connecting the inductance 205 to the serial arm resonator Sc, an insertion loss is sacrificed to provide an attenuation pole on the outer side of the high pass in the bass band, thereby achieving the increase in the attenuation. However, as is apparent from Fig. 21, even when the above-mentioned attenuation pole is formed, the attenuation on the outer side of the high pass in the bass band has managed to merely satisfy 40 dB.

Furthermore, as shown in Fig. 23, the isolation characteristic in 2110 MHz to 2170 MHz corresponding to the reception-side pass band is merely about 40 dB as well. On the other hand, the characteristics of the duplexer 201 vary depending on the temperature. Therefore, it is understood that the attenuation the reception-side pass band cannot be reliably kept equal to or larger than 40 dB over the temperature range where in the duplexer 201 is used.

In view of the above-described related-art circumstances, it is an object of the present invention to provide a duplexer constructed by using a plurality of surface acoustic wave elements in which not only the electric power resistance can be increased but also the out-of-band attenuation and the isolation characteristic can be set satisfactorily large, and a communication device using the duplexer.

The present invention relates to a duplexer, including a transmission-side band filter and a reception-side band filter respectively constructed by connecting a plurality of surface acoustic wave resonators to form a ladder circuit, characterized in that the surface acoustic wave resonator includes a 47° to 58° rotated, Y-cut, X-propagating $LiNbO_3$ substrate and an IDT electrode formed on the $LiNbO_3$ substrate, that the IDT electrode includes a Ti foundation electrode layer formed on the $LiNbO_3$ substrate and an Al electrode layer formed on the Ti foundation electrode layer, and that a (111) face of the Al electrode layer, a (001) face or (100) face of the Ti foundation electrode layer, and a (001) face of the $LiNbO_3$ substrate are aligned parallel.

According to a particular aspect of the duplexer in accordance with the present invention, the Ti foundation electrode layer is formed through epitaxial growth on the $LiNbO_3$ substrate and the Al electrode layer is formed through epitaxial growth on the Ti foundation electrode layer.

According to another particular aspect of the duplexer in accordance with the present invention, in the reception-side band filter, a first inductance is inserted in parallel with respect to at least one serial arm resonator connected to a serial arm of the ladder circuit among the plurality of surface acoustic wave resonators, and in the transmission-

side band filter, a second inductance is inserted between a parallel arm resonator connected to a parallel arm of the ladder circuit among the plurality of surface acoustic wave resonators and a ground potential.

According to another particular aspect of the duplexer in accordance with the present invention, it is characterized in that the first inductance and the second inductance are respectively constructed by at least one of a wire bonding used for electrical connection in the duplexer, a line embedded in the duplexer, and an external coil part.

A communication device according to the present invention includes the duplexer constructed on the basis of the present invention, in which the duplexer includes an antennal terminal, a third inductance is inserted between the antennal terminal and the antenna, and the duplexer further includes a capacitor connected between a connection point between the third inductance and the antennal and the ground potential.

The duplexer according to the present invention includes the transmission-side band filter constructed by connecting the plurality of surface acoustic wave resonators to form a ladder circuit and the reception-side band filter constructed by connecting the plurality of surface acoustic wave resonators to form a ladder circuit. Then, each of the surface acoustic wave resonators has the Ti foundation

electrode layer formed on the $LiNbO_3$ substrate and the Al electrode layer formed on the Ti foundation electrode layer, and the (111) face of the Al electrode layer, the (001) face or (100) face of the Ti foundation electrode layer, and the (001) face of the $LiNbO_3$ substrate are aligned parallel. Thus, each of the surface acoustic wave resonators has a sufficient electric power resistance. Therefore, the electric power resistance of the duplexer can be increased.

Moreover, the 47° to 58° rotated, Y-cut, X-propagating $LiNbO_3$ substrate is used, and as is apparent from experiments to be described later, not only the electric power resistance can be increased but also the attenuation on the high pass side of the pass band can be set sufficiently large. At the same time, it is possible to effectively improve the isolation characteristic as well.

As a result, according to the present invention, for example, it is possible to provide the duplexer which is suitably used as the duplexer of the mobile phone based on the W-CDMA method, is superior in the electric power resistance, and has the large attenuation and isolation characteristic.

Preferably, the Ti foundation electrode layer and the Al electrode layer are formed through epitaxial growth, and in that case, the (111) face of the Al electrode layer and the (001) face or (100) face Ti foundation electrode layer

are aligned parallel with respect to the (001) face of $LiNbO_3$.

In the reception-side band filter, as the first inductance is inserted in parallel with respect to at least one serial arm resonator connected to the serial arm among the plurality of surface acoustic wave resonators connected in a ladder form, when the second inductance is inserted between the parallel arm resonator connected to the parallel arm of the ladder circuit and the ground potential, the out-of-band attenuation can be set still larger.

When the first inductance inserted in parallel with respect to the serial arm resonator of the reception-side band filter and the second inductance between the parallel arm resonator of the transmission-side band filter and the ground potential are respectively constructed by at least one of the wire bonding wire bonding used for electrical connection in the duplexer, the line embedded in the duplexer, and the external coil part, it is possible to construct the first and second inductances without the necessity of external parts or other parts. Therefore, the duplexer of the present invention can be provided without causing the increase in the number of parts of the duplexer.

The communication device according to the present invention has the duplexer constructed on the basis of the present invention, the third inductance is inserted between

the antenna terminal and the antenna, and the capacitor is connected between a connection point between the third inductance and the antenna and the ground potential. Therefore, it is possible to effectively improve the attenuation outside the pass band and the isolation characteristic.

Brief Description of the Drawings

Fig. 1(a) is a circuit diagram for describing a circuit configuration of a duplexer according to a first embodiment of the present invention, and Fig. 1(b) is a partially notched frontal cross-sectional view showing a construction of an IDT electrode.

Fig. 2 is a schematic plan view showing a specific configuration of the duplexer according to the first embodiment.

Fig. 3 is a schematic plan cross-sectional view of a positional construction at an intermediate height of the package for the duplexer shown in Fig. 2.

Fig. 4 is a schematic plan cross-sectional view of the duplexer according to the first embodiment.

Fig. 5(a) is a plan view of an acoustic surface wave element chip used in the first embodiment, and Figs. 5(b) and 5(c) are respectively schematic plan views showing electrode constructions of a serial arm resonator and a

parallel arm resonator.

Fig. 6 is a graph illustrating a frequency characteristic of a transmission-side band filter of the duplexer according to the first embodiment.

Fig. 7 is a graph illustrating a frequency characteristic of a reception-side band filter of the duplexer according to the first embodiment.

Fig. 8 is a graph illustrating an isolation characteristic of the duplexer according to the first embodiment.

Fig. 9 is a graph illustrating a frequency characteristic of a transmission-side band filter of a duplexer using an $LiNbO_3$ substrate with a cut angle of 45° prepared for comparison.

Fig. 10 is a graph illustrating a frequency characteristic of a reception-side band filter of a duplexer using the $LiNbO_3$ substrate with a cut angle of 45° prepared for comparison.

Fig. 11 is a graph illustrating an isolation characteristic of a duplexer using the $LiNbO_3$ substrate with a cut angle of 45°.

Fig. 12 is a graph illustrating a relation between a cut angle of an $LiNbO_3$ substrate and an electromechanical coupling coefficient.

Fig. 13 is a circuit diagram for describing a circuit

configuration of a duplexer according to a second embodiment.

Fig. 14 is a graph illustrating a frequency characteristic of a reception-side band filter of the duplexer according to the second embodiment.

Fig. 15 is a graph illustrating a frequency characteristic of a transmission-side band filter of the duplexer according to the second embodiment.

Fig. 16 is a graph illustrating an isolation characteristic of the duplexer according to the second embodiment.

Fig. 17 is a schematic plan view for describing a specific configuration of the duplexer according to the second embodiment.

Fig. 18 is a circuit diagram for describing a modified example of the duplexer according to the second embodiment.

Fig. 19 is a simplified frontal cross-sectional view for describing a modified example of the duplexer according to the first embodiment.

Fig. 20 is a circuit diagram for describing an example of a related-art duplexer.

Fig. 21 is a graph illustrating a frequency characteristic of a transmission-side band filter of the related-art duplexer.

Fig. 22 is a graph illustrating a frequency characteristic of a reception-side band filter of the

related-art duplexer.

Fig. 23 is a graph illustrating an isolation characteristic of the related-art duplexer.

Reference Numerals

1 cylinder duplexer

1a antenna terminal

1A transmission-side band filter

1B reception-side band filter

2 antenna

3 transmission terminal

4 reception terminal

5, 6 second inductance

7 first inductance

8 third inductance

9 capacitor

11 $LiNbO_3$ substrate

12 IDT electrode

12a Ti foundation electrode layer

12b Al electrode layer

21 duplexer

21a antenna terminal

21A transmission-side band filter

21B reception-side band filter

25 second inductance

27 first inductance

31 package

32a the concave portion

33 cover member

34 acoustic surface wave element chip

41 duplexer

42 multilayer substrate

43, 44 electrode land

45, 46 internal electrode

47a, 47b via hole electrode

48a, 48b via hole electrode

49, 50 internal electrode

51a, 51b via hole electrode

52, 53 terminal electrode

54 $LiNbO_3$ substrate

55 frame member

56 cover member

S1 to S6 serial arm resonator

P1 to P4 parallel arm resonator

Best Mode for Carrying Out the Invention

Hereinafter with reference to the drawings, the present invention will become apparent by way of describing specific embodiments of the present invention.

Fig. 1 is a circuit diagram for describing a circuit

configuration of a duplexer according to a first embodiment of the present invention. It should be noted that an area surrounded by a dashed line corresponds to a duplexer area of this embodiment in Fig. 1.

A duplexer 1 includes an antenna terminal 1a. Connected to the antenna terminal 1a are a transmission-side band filter 1A and a reception-side band filter 1B. The transmission-side band filter 1A is connected to a transmission terminal 3, and the reception-side band filter 1B is connected to a reception terminal 4.

In the transmission-side band filter 1A, a plurality of surface acoustic wave resonators are connected to achieve a ladder circuit. That is, the transmission-side band filter 1A includes a plurality of serial arm resonators S1 to S3 each of which is composed of a surface acoustic wave resonator and parallel arm resonators P1 and P2. Inductances 5 and 6 are connected between the parallel arm resonators P1 and P2 and a ground potential. The inductances 5 and 6 construct second inductances of the present invention. It should be noted that according to this embodiment, the inductances 5 and 6 are constructed by a wire bonding or a line arranged in the duplexer 1.

On the other hand, the reception-side band filter 1B includes a configuration where a plurality of surface acoustic wave resonators are connected to construct a ladder

circuit. Herein, a plurality of serial arm resonators S4 to S6 and a plurality of parallel arm resonators P3 and P4 are provided. Then, the serial arm resonator S6 in the last pole is connected in parallel with respect to an first inductance 7. With the connection of the first inductance 7, in the reception-side band filter, an attenuation pole is formed on the low pass side of the pass band, and accordingly the increase in the attenuation of the reception-side band filter 1B on the low pass side of the pass band is achieved.

The first and second inductances 5 to 7 may be constructed by an external coil part.

In the meantime however, the first and second inductances 5, 6 and 7 are preferably constructed by at least one of the wire bonding and the line arranged in the duplexer. In that case, additional provision of external parts such as the coil part is not necessary. Therefore, the first and second inductances 5 to 7 can be constructed without causing the increase in the number of parts.

On the other hand, connected between the antenna terminal 1a and an antenna 2 is a third inductance 8. Then, connected between a connection point between the third inductance 8 and the antenna 2 and the ground potential is a capacitor 9. The third inductance 8 and the capacitor 9 are constructed by a part externally attached to the duplexer 1.

Examples of such external part include a chip coil and a chip capacitor.

According to this embodiment, as described above, the first and second inductances 5 to 7 are constructed by the wire bonding and/or the line in the duplexer, whereby the package area can be reduced to 90.25% and the mounting area can be reduced to 80% with respect to the related-art products.

Fig. 1(b) is a schematic frontal cross-sectional view showing the electrode construction in the duplexer 1 described above, and a part of the electrode of the serial arm resonator S1 is schematically shown as the representative example of the electrode construction. The serial arm resonator S1 includes a 47° to 58° rotated, Y-cut, X-propagating $LiNbO_3$ substrate 11 and an IDT electrode 12 formed on the $LiNbO_3$ substrate 11. Then, the IDT electrode 12 includes a Ti foundation electrode layer foundation electrode layer formed through epitaxial growth on the $LiNbO_3$ substrate and an Al electrode layer 12b formed through epitaxial growth on the Ti foundation electrode layer foundation electrode layer. Furthermore, the (111) face of the Al electrode layer, the (001) face or the (100) face of the Ti foundation electrode layer, and the (001) face of the $LiNbO_3$ substrate are aligned parallel. Therefore, as the IDT electrode 12 has a similar

construction to that of the IDT electrode of the surface acoustic wave elements described in Patent Document 1 mentioned above, the electric power resistance is superior. It should be noted that although Fig. 1 (b) schematically shows the electrode construction of the serial arm resonator S1, the other serial arm resonators S2, S3, and S4 to S6 and the parallel arm resonators P1 to P4 are constructed by using the IDT electrode with the similar crystal structure. Therefore, the duplexer 1 is superior in the electric power resistance.

Next, a description will be given of a specific configuration of the duplexer 1 according to this embodiment.

Fig. 2 is a specific plan view of the duplexer according to the first embodiment, and Fig. 3 is a plan cross-sectional view thereof at the intermediate height.

The duplexer 1 includes a package 31. The package 31 is constructed by a multilayer package substrate composed of an insulating ceramics as aluminum. That is, as shown in a schematic cross-sectional view of Fig. 4, the package 31 is a multilayer package substrate composed by laminating a plurality of insulating ceramic layers.

The package 31 includes an opening 31a opened upward. As shown in Fig. 4, the concave portion 31a is structured while being closed by a cover member 32. Graphic representation for the cover member 32 is omitted in Fig. 2.

In the concave portion 31a, an acoustic surface wave element chip 33 is accommodated as shown in Fig. 2.

The acoustic surface wave element chip 33 is shown in a plan view of Fig. 5(a). The acoustic surface wave element chip 33 is constructed using a rectangular $LiNbO_3$ substrate 11. As described above, according to the first embodiment, as the $LiNbO_3$ substrate 11, a 55° rotated, Y-cut $LiNbO_3$ substrate is used.

Then, the IDT electrode with the cross-sectional construction shown in Fig. 1(b) is formed on the $LiNbO_3$ substrate 11 to form the serial arm resonators S1 to S6 and the parallel arm resonators P1 to P4. In Fig. 5(a), the graphic representation for the electrode construction of the serial arm resonator and the parallel arm resonator is simplified, whereas Fig. 5(b) shows the electrode construction of the serial arm resonator S6 in a schematic plan view. That is, as shown in Fig. 5(b), the serial arm resonator S6 is a one terminal pair surface acoustic wave resonator including the IDT electrode 35 and reflectors 36 and 37 on both sides of the surface acoustic wave propagating direction of the IDT electrode 35.

It should be noted that each of other serial arm resonators S3 and S5 and the parallel arm resonators P1 to P4 is similarly composed of a one terminal pair surface acoustic wave resonator by arranging reflectors on both the

directions of the surface acoustic wave propagating direction of the IDT electrode. On the other hand, as shown in Fig. 5(c), the serial arm resonator S2 includes an IDT electrode 38 to which a pair of IDT electrodes are connected and reflectors 39 and 40 arranged on both the directions of the surface acoustic wave propagating direction of the IDT electrode 38. That is, the serial arm resonator S2 has a construction where two serial arm resonators S2a and S2b are connected. In a similar manner, the serial arm resonator S1 and the serial arm resonator S4 also have a construction where serial arm resonators S1a and S1b and serial arm resonators S4a and S4b are respectively connected.

In the meantime however, in the present invention, the serial arm resonator or the parallel arm resonator constructing the ladder circuit may be composed of a surface acoustic wave resonator having a single pole construction or a plural pole construction with the any number of poles.

As shown in Fig. 5 (a), formed on the $LiNbO_3$ substrate 11 are the serial arm resonators S1 to S6 and the parallel arm resonators P1 to P4, which are respectively electrically connected to construct the transmission-side band filter 1A and the reception-side band filter 1B. That is, as shown in Fig. 1, in the transmission-side band filter 1A, the serial arm resonators S1 to S3 and the parallel arm resonators P1 and P2 are electrically connected to construct a ladder

circuit. In a similar manner, in the reception-side band filter 1B, the serial arm resonators S4 to S6 and the parallel arm resonators P1 and P2 are electrically connected to construct a ladder circuit.

Furthermore, according to the first embodiment, the second inductances 5 and 6 are constructed by the bonding wire and the coil patterns in the package. To be more specific, as shown in Fig. 3, the inductances 5 and 6 are constructed by coil patterns 5a and 6a formed at the intermediate height positions of the package 31 and bonding wires 41 and 42 shown in Fig. 4, and the like. Then, the first inductance 7 is constructed by the bonding wire and the coil patterns in the package shown in Fig. 2. In this manner, as the coil patterns 5a, 6a, and 7a, the bonding wires 41 and 42 provided inside the package, and the like are used, the first and second inductances 5, 6 and 7 can be constructed without increasing the number of parts.

The duplexer 1 according to this embodiment is not only superior in the electric power resistance and but also is constructed by using a 47° to 58° rotated, Y-cut, X-propagating $LiNbO_3$ substrate 11, whereby the out-of-band attenuation is sufficiently large and the isolation characteristic is satisfactory as well. This will be described on the basis of specific experiment examples.

Each of the serial arm resonators S1 to S6 and the

parallel arm resonators P1 to P4 is composed of the surface acoustic wave resonator having the IDT electrode of the above-mentioned construction formed on the 55° rotated, Y-cut, X-propagating $LiNbO_3$ substrate 11. It should be noted that the thickness of the Ti foundation electrode layer is set to 10 nm and the thickness of the Al electrode layer is set to 92 nm.

Specifications of the serial arm resonators S1 to S6 and the parallel arm resonators P1 to P4 are shown in Tables 1 and 2 below. In the Tables 1 and 2 below, the number of the electrode fingers of the reflector, the duty ratio of the IDT electrode, the size of a gap between the IDT and the reflector, the cross width and log of the electrode fingers of the IDT electrode, and a wavelength λ.

Table 1

	The number of reflector fingers	Duty ratio	Gap	Cross width	IDT log	λ
S1	15	0. 4	0. 5	40	140	2. 1743
P1	15	0. 4	0. 45	40	80	2. 3016
S2a	15	0. 4	0. 5	55	200	2. 1533
S2b	15	0. 4	0. 5	55	200	2. 1533
P2	15	0. 4	0. 45	40	80	2. 2957
S3a	15	0. 4	0. 5	40	160	2. 1743
S3b	15	0. 4	0. 5	40	160	2. 1743

Table 2

	The number of reflector fingers	Duty ratio	Gap	Cross width	IDT log	λ
S4a	15	0. 4	0. 5	40	65	1. 9648
S4b	15	0. 4	0. 5	40	65	1. 9648
P3	15	0. 4	0. 45	65	70	2. 1146
S5	15	0. 4	0. 5	50	80	1. 9703
P4	15	0. 4	0. 45	55	70	2. 1146
S6	15	0. 4	0. 5	50	85	2. 0057

Then, the transmission-side band filter 1A and the reception-side band filter 1B are fabricated so that the intermediate frequency of the transmission-side band filter 1A is set to 1945 MHz and the intermediate frequency of the reception-side band filter 1B is set to 2140 MHz. A coil pattern with the inductance of 2.7 nH is formed as the coil pattern to construct the second inductances 5 and 6 so that the inductance of 3.3 nH is attained by the coil pattern and the bonding wire with the inductance of 0.6 nH. Also, regarding the first inductance 7, the inductance value of the coil pattern is set to 0.8 nH and the inductance value of the bonding wire the inductance value is set to 1.2 nH, whereby the inductance value of the first inductance 7 is set to 1.9 nH.

The value of the third inductance 8 is set to 3.3 nH and the capacity of the capacitor 9 is set to 1.3 pF. Frequency characteristics of the duplexer 1 thus fabricated according to this embodiment are measured. Figs. 6 to 8

show the result. Then, the pass band of the transmission-side band filter 1A is 1920 to 1980 MHz and the pass band of the reception-side band filter 1B is 2110 to 2170 MHz.

Fig. 6 shows a frequency characteristic of the transmission-side band filter 1A, Fig. 7 shows a frequency characteristic of the reception-side band filter 1B, and Fig. 8 shows the isolation characteristic of the duplexer. It should be noted that, the frequency characteristics on the lower sides in Figs. 6 and 7 represent the frequency characteristics in pass bands based on the right-hand side scale shown through magnification of the corresponding frequency characteristics.

As is apparent from Fig. 6, it is understood that in the transmission-side band filter 1A, the attenuation on the high pass side of the pass band (reception-side band) is 47 dB, and it is understood that the value is by far larger than 40 dB as demand characteristics. Similarly, as is apparent from Figs. 7 and 8, it is understood that in the pass band of the reception-side band filter 1B, the attenuation of the isolation characteristic obtains at least 48 dB.

That is, as is apparent from Figs. 6 to 8, it is understood that in the duplexer, not only the electric power resistance is increased, but also the out-of-band attenuation, in particular, the attenuation on the high pass

side of the pass band of the transmission-side band filter 1A can be significantly improved and at the same time the isolation characteristic can also be significantly improved.

As described above, in the duplexer 1, the out-of-band attenuation and the isolation characteristic is significantly improved, because a $LiNbO_3$ substrate with a cut angle falling in a range from 47° to 58° is used for the $LiNbO_3$ substrate 11. This will be described on the basis of specific experiment examples. The characteristics of the above-described related-art product shown in Figs. 21 to 23 correspond to the characteristics of the duplexer similarly constructed as in the first embodiment except that the cut angle of the $LiNbO_3$ substrate is 64° and the serial arm resonators S1 to S3 and S4 to S6 and the parallel arm resonators P1, P2, P3, and P4 are constructed as shown in Tables 3 and 4 below. At this time, when the cut angle of the substrate is varied, it is of course necessary to vary the values of the duty ratio, the cross width, and the like with which optimal characteristics (characteristics at low loss and high attenuation) can be obtained. Therefore, to conduct characteristic comparison in view of the cut angle, the optimal characteristics in the 55° rotated, Y-cut, X-propagating $LiNbO_3$ substrate and the optimal characteristics in the 64° rotated, Y-cut, X-propagating $LiNbO_3$ substrate need be to compared with each other. For this reason, the

duty ratio, the cross width, and the like shown in Tables 1 and 2, with which the optimal characteristics can be obtained in the 55° rotated, Y-cut, X-propagating $LiNbO_3$ substrate are different from the duty ratio, the cross width, and the like shown in Tables 3 and 4, with which the optimal characteristics can be obtained in the 64° rotated, Y-cut, X-propagating $LiNbO_3$ substrate. Then, as described with reference to Figs. 21 to 23, in the duplexer 201, the pass band attenuation and the isolation characteristic of the transmission-side band filter are not sufficiently large.

Table 3

	The number of reflector fingers	Duty ratio	Gap	Cross width	IDT log	λ
S1	14	0. 390	0. 5	60	196	2. 1450
P1	14	0. 347	0. 5	54. 3	92	2. 2525
S2a	14	0. 390	0. 5	32. 5	200	2. 1450
S2b	14	0. 390	0. 5	92	200	2. 1450
P2a	14	0. 347	0. 5	41. 9	90	2. 2526
P2b	14	0. 347	0. 5	41. 9	90	2. 2526
S3a	14	0. 390	0. 5	40	165	2. 1450
S3b	14	0. 390	0. 5	36	165	2. 1450

Table 4

	The number of reflector fingers	Duty ratio	Gap	Cross width	IDT log	λ
S4a	14	0. 389	0. 5	31. 5	125	1. 9559
S4b	14	0. 389	0. 5	35	125	1. 9559
S4c	14	0. 389	0. 5	40	125	1. 9559
P3	14	0. 361	0. 5	41. 2	114	2. 0896
S5	14	0. 390	0. 5	28	116	1. 9967
P4	14	0. 361	0. 5	41. 2	114	2. 0896
S6a	14	0. 390	0. 5	75	165	1. 9967
S6b	14	0. 390	0. 5	53	165	1. 9967

On the other hand, for further comparison, a duplexer constructed as in the embodiment described above except that the cut angle of the $LiNbO_3$ substrate is 45° is fabricated and the frequency characteristic is measured. Figs. 9 to 11 show the results.

Fig. 9 shows the frequency characteristic of a transmission-side band filter of a duplexer for the comparison example, Fig. 10 shows the frequency characteristic of a reception-side band filter, and Fig. 11 shows the isolation characteristic. It should be noted that the frequency characteristics on the lower sides in Figs. 9 and 10 represent the frequency characteristics in pass bands based on the right-hand side scale shown through magnification of the corresponding frequency characteristics.

As is apparent from Figs. 9, when the $LiNbO_3$ substrate with a cut angle of 45° is used, the attenuation on the high pass side of the pass band the reception-side band filter

reaches just above 40 dB, and it is understood that the attenuation is lower as compared with the duplexer 1 according to the embodiment described above. Also, from Figs. 10 and 11, the isolation characteristic of the reception-side band filter is also slightly above 40 dB, and it is understood that the isolation characteristic is not sufficiently large.

As is apparent by comparing the result of the embodiment described above with the result from the comparison examples using the $LiNbO_3$ substrate with the cut angle of 45° shown in Figs. 9 to 11 and the result from the related-art examples using the $LiNbO_3$ substrate with the cut angle of 64° described with reference to Figs. 20 to 23, when the rotation angle of the $LiNbO_3$ substrate is set to 55°, the out-of-band attenuation and the isolation characteristic may be effectively ameliorated in the duplexer 1. Then, based on the experiments conducted by the inventors of the present invention, in the duplexer 1 described above, when the cut angle of the $LiNbO_3$ substrate is set with in a range from 47° to 58°, satisfactory characteristics can be obtained as in the embodiment described above.

As shown in Figs. 9 to 11, as the cut angle is smaller, the out-of-band attenuation cannot be set sufficiently large. This is because, as the cut angle is smaller, the insertion

loss is increased, and an attenuation constant α is larger. As the electromechanical coupling coefficient is too large, steepness cannot be obtained, thereby degrading the attenuation (the band selectivity is degraded). Therefore, in consideration with the change in characteristics due to the temperature, the sufficiently large out-of-band attenuation and isolation characteristic cannot be obtained.

In addition, as the cut angle is smaller, an angle between the Y axis and a normal to the substrate becomes small, and the epitaxial growth of electrode films is difficult. Therefore, the formation of the electrode with the high electric power resistance is also difficult. The lower limit of the cut angle where the electrode films may be formed through the epitaxial growth is around 47° based on the experiences conducted by the inventors of the present invention. That is, when the $LiNbO_3$ substrate whose cut angle is smaller than 47° is used, it was impossible to form the electrode films through the epitaxial growth. Therefore, as described above, the lower limit of the cut angle for the $LiNbO_3$ substrate is 47°.

On the other hand, in consideration with the use temperature range of the duplexer, the upper limit of the cut angle for satisfying the attenuation and the isolation characteristic is 58°. When the $LiNbO_3$ substrate whose cut angle is larger than 58° is used, the out-of-band

attenuation cannot be set sufficiently large. Therefore, for example, in the transmission-side band filter, the inductance element connected in parallel with respect to the serial arm resonators cannot be omitted.

As described above, according to this embodiment, the electrode for increasing the electric power resistance employs the rotated, Y-cut, X-propagating $LiNbO_3$ substrate with a cut angle of 47° to 58°, the out-of-band attenuation and the isolation characteristic are effectively ameliorated. In the related art, it has been thought that when the $LiNbO_3$ substrate is used as a piezoelectric substrate for the surface acoustic wave resonator, a large cut angle is preferable. Fig. 12 shows a relation between the cut angle of the rotated, Y-cut $LiNbO_3$ substrate and the electromechanical coupling coefficient of the surface acoustic wave. Herein, the duty ratio of the electrode is set to 0.4 and the normalized thickness of the electrode (H/λ) is set to 5.15. It should be noted that H denotes the thickness of the electrode and H denotes the wavelength of the surface acoustic wave.

As is apparent from Fig. 12, it is understood that as the cut angle exceeds 40° to 60° and is further larger, an electromechanical coupling coefficient K becomes small. Therefore, to enlarge the out-of-band attenuation in the neighborhood of the band, it has been thought that desirably,

the cut angle is set large and the band width is set small. That is, in the related art, to enlarge the out-of-band attenuation, it has been thought that the larger the cut angle of the rotated, Y-cut $LiNbO_3$ substrate, the more desirable.

Also, in the related art, it has been thought that when the rotated, Y-cut $LiNbO_3$ substrate is used, as the cut angle is larger, the propagation loss α is smaller, whereby the insertion loss can be set smaller and at the same time the out-of-band attenuation can be enlarged.

That is, in despite of the technical common knowledge of the related art where it is desirable to set the cut angle as large as possible when the duplexer is constructed by using the rotated, Y-cut $LiNbO_3$ substrate to enlarge the out-of-band attenuation, that is, the cut angle is desirably larger than 60°, it is characterized in the present invention that the cut angle is set to equal to or smaller than 58°. Then, by setting the cut angle in the particular range from 47° to 58°, the electrode superior in the electric power resistance can be formed, also furthermore it is possible to set the out-of-band attenuation and the isolation characteristic sufficiently large.

Thus, according to the embodiment described above, as the sufficient out-of-band attenuation can be obtained, the number of the inductance elements used for ensuring the

attenuation can be reduced. That is, with the related-art duplexer shown in Fig. 20, while the inductance 205 is connected in parallel with respect to the serial arm resonator Sc in the transmission-side band filter 201A, it is possible to omit the inductance 205. Therefore, the downsizing of the duplexer can be achieved.

In the meantime however, as in the embodiment described above, the first inductance 7 is connected in parallel with respect to the serial arm resonator S6, and accordingly the out-of-band attenuation may be further enlarged. It should be noted that in the related art, even when the $LiNbO_3$ substrate whose cut angle is larger than 60°, in actual the sufficient out-of-band attenuation cannot be obtained and it is actually impossible to omit the inductance 205 described above.

Fig. 13 is a circuit diagram for describing a duplexer according to a second embodiment of the present invention. It should be noted that in Fig. 13 an area surrounded by a dashed line corresponds to a duplexer construction area of this embodiment.

A duplexer 21 includes an antenna terminal 21a. Connected to the antenna terminal 21a are a transmission-side band filter 21A and a reception-side band filter 21B. The transmission-side band filter 21A is connected to the transmission terminal 3, and the reception-side band filter

21B is connected to the reception terminal 4. The transmission-side band filter 21A and the reception-side band filter 21B respectively have the construction where the five surface acoustic wave resonators are connected to realize the ladder circuit similarly to the transmission-side band filter 1A and the reception-side band filter 1B of the first embodiment. Therefore, the same part will be given of the same reference numerals and the description for the first embodiment is to be incorporated.

According to the second embodiment, in the transmission-side band filter 21A, connected between the parallel arm resonators P1 and P2 and the ground potential is a second inductance 25. Herein, the second inductance 25 is constructed in the duplexer 21.

The second inductance 25 may be composed of the wire bonding or the line used in the duplexer 21. In the meantime however, the second inductance 25 may be composed of the coil part or the like as the part externally attached to the duplexer 21.

Then, in the reception-side band filter 21B, a first inductance 27 is connected in parallel with respected to the serial arm resonator S6 in the last pole. With the connection of the first inductance 27, in the reception-side band filter 21B, the attenuation pole is formed on the low pass side of the pass band. Accordingly, the increase in

the attenuation of the reception-side band filter 21B on the low pass side of the pass band is achieved.

The first inductance 27 may be composed of the coil part or may be composed of the wire bonding or the line in the duplexer.

In the duplexer 21 as well, connected between the antenna terminal 21a and the antenna 2 are the third inductance 8 and the capacitor 9 as in the case of the first embodiment.

In this embodiment also, when the first and second inductances 25 and 27 are composed of at least one of the wire bonding and the line arranged in the duplexer, additional provision of the other coil part is not necessary. Therefore without causing the increase in the number of parts, the first and second inductances 25 and 27 can be constructed the number of parts.

According to this embodiment, the duplexer 21 is composed of the 50° rotated, Y-cut, X-propagating $LiNbO_3$ substrate, the serial arm resonators S1 to S6 and the parallel arm resonators P1 to P4 are constructed as in the case of the first embodiment. Each of the serial arm resonators S1 to S6 and the parallel arm resonators P1 to P4 is composed of the IDT electrode having the electrode construction where the Ti foundation electrode layer and the Al electrode layer are laminated. Therefore, the

construction of the IDT electrode will be omitted by incorporating the description of the electrode construction with reference to Fig. 1(b) in the first embodiment.

The duplexer 21 of the second embodiment described above is fabricated in the following procedure, and the frequency characteristic is measured.

The serial arm resonators S1 to S6 and the parallel arm resonators P1 to P4 are constructed as shown in Tables 5 and 6 below.

In an embodiment described below, the serial arm resonators S1, S2, and S4 have double a pole construction of the serial arm resonators S1a and S1b, S2a and S2b, and S4a and S4b.

Table 5

	The number of reflector fingers	Duty ratio	Gap	Cross width	IDT log	λ
S1	15	0. 4	0. 5	44	120	2. 187421
P1	15	0. 4	0. 4	44	80	2. 322526
S2a	15	0. 4	0. 5	45	100	2. 160974
S2b	15	0. 4	0. 5	45	100	2. 160974
P2	15	0. 4	0. 4	44	80	2. 328572
S3a	15	0. 4	0. 5	44	200	2. 187421
S3b	15	0. 4	0. 5	44	200	2. 187421

Table 6

	The number of reflector fingers	Duty ratio	Gap	Cross width	IDT log	λ
S4a	15	0. 4	0. 5	35	65	1. 958722
S4b	15	0. 4	0. 5	35	65	1. 958722
P3	15	0. 4	0. 45	50	90	2. 103972
S5	15	0. 4	0. 5	30	60	1. 964194
P4	15	0. 4	0. 45	45	70	2. 099018
S6	15	0. 4	0. 5	50	85	2. 003944

Then, the second inductance 25 is composed of the bonding wire in the duplexer 21, and the inductance value is set to 0.6 nH. The first inductance 27 is constructed by the coil pattern and the bonding wire formed inside the duplexer 21. The inductance value of the coil pattern is set to 0.8 nH and the inductance value of the bonding wire is set to 1.2 nH. That is, the inductance 27 is configured to have the inductance value of 2.0 nH.

The inductance value of the inductance 8 externally attached is set to 3.3 nH, and the electrostatic capacity of the capacitor 9 is set to 1.3 pF. Frequency characteristics of the duplexer 21 constructed as described above are shown in Figs. 14 to 16. Fig. 14 shows a frequency characteristic of the transmission-side band filter of the duplexer 21, Fig. 15 shows a frequency characteristic of the reception-side band filter, and Fig. 16 shows the isolation characteristic. It should be noted that the frequency characteristics on the lower sides in Figs. 14 and 15 represent the frequency

characteristics in pass bands based on the right-hand side scale shown through magnification of the corresponding frequency characteristics.

As is apparent from Fig. 14, even when the $LiNbO_3$ substrate with a cut angle of 50° is used, as in the case of the first embodiment, the attenuation on the high pass side of the pass band (reception-side band) of the transmission-side band filter can be set larger than 40 dB. Also, as is apparent from Figs. 15 and 16, the isolation characteristic in the reception-side band is also by far larger than 40 dB.

Fig. 17 is a schematic plan view of the duplexer according to the second embodiment. In the duplexer 21 too, as in the case of the first embodiment, the second inductance can be formed by forming a coil pattern 27a in the package 31. Also, by using a bonding wire 25a, the first inductance 25 can be constructed. In this manner, by composing the second and first inductances 25 and 27 of the coil pattern and the bonding wire in the package constructing the duplexer 21, the downsizing of the duplexer 21 can be achieved without causing the increase in the number of parts.

It should be noted that according to the second embodiment, the first inductance 27 is connected in parallel with respect to the serial arm resonator S6 in the last pole of the reception-side band filter, but as shown in Fig. 18,

the first inductance 27A may be connected in parallel with respect to the serial arm resonator S5 in the center.

Furthermore, according to the embodiment described above, for achieving the impedance matching among the antenna, the transmission-side band filter, and the reception-side band filter, there is used a matching circuit where an inductance is inserted between an antenna terminal and an antenna and also a capacitor is connected between the antenna and a ground. However, as long as the impedance matching among the antenna, the transmission-side band filter, and the reception-side band filter can be achieved, any matching circuit construction other than the above may be adopted. For example, a matching circuit where a capacitor is connected between an antenna terminal and an antenna and also an inductance is connected between the antenna and a ground or a matching circuit where an inductance is simply connected between an antenna and a ground may also be adopted.

Then, a duplexer 41 as a modified example shown in Fig. 19 adopts the similar package construction as that of the duplexer 1. In the meantime however, herein, a multilayer substrate 42 is used as a package member. Formed on the upper face of the multilayer substrate 42 are electrode lands 43 and 44. The electrode lands 43 and 44 are electrically connected to internal electrodes 45 and 46 for

inductance constructions arranged inside the multilayer substrate 42 via hole electrodes 47a and 47b. In addition, the internal electrodes are connected to internal electrodes 49 and 50 for inductance constructions via hole electrodes 48a and 48b. The internal electrodes 49 and 50 are connected to terminal electrodes 52 and 53 via hole electrodes 51a and 51b. In this manner, the inductance may be constructed inside the multilayer substrate 42 and a SAW chip constructed by using an $LiNbO_3$ substrate 54 constructed by using a flip chip bonding method may be mounted on the multilayer substrate 42.

It should be noted that a frame member 55 made of the same material is integrally provided on the upper face of the multilayer substrate 42. Then, a cover member 56 for sealing the upper side of the frame member 55 is jointed on the upper face of the frame member 55.